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2. TITLE OF THE INVENTION

SYSTEM AND METHOD TO DETERMINE OPTIMAL RESIST THICKNESS AND COMPARE SWING CURVE AMPLITUDES

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System and Method to Determine Optimal Resist Thickness and

Compare Swing Curve Amplitudes

Determination of Optimal Resist Thickness

Background

Most semiconductor devices are fabricated by coating thin layers of photosensitive materials (resists) onto various substrates. These thin layers are exposed to radiation (usually ultraviolet) to induce chemical reactions which create regions that are either base soluble or base insoluble. Since these films are on the same order of thickness as the actinic radiation, the amount of light coupled into the resist is very dependent on the thickness. The effect of resist thickness on linewidth is known as the "swing curve" effect. In general, the swing curve effect is sinusoidal. It is very desirable to operate processes at a maxima or minima of the swing curve to minimize variations of resist thickness on linewidth for critical applications.

There are several methods to determine the resist thickness at the maxima of the swing curve. The first is to prepare wafers of varying resist thickness on well known substrates, typically silicon, measure the resist thickness and then expose and develop the wafers. After development, a particular feature is measured on all the wafers and its dimension is tabulated or plotted as a function of resist thickness. This generally results in a sinusoidal curve. A second method is to expose a pattern of increasing exposure doses on wafers of varying thicknesses and record the dose for each wafer at which the resist clears or has the same optically measured thickness. A single wafer version of this method is to induce topography, by selective etching, so that when coated there is a variation of thicknesses across the wafer. The resist thickness in these regions is measured and then the wafer is exposed, developed and measured. Linewidth or dose to clear measurements are compared to the resist thicknesses before exposure. Lastly, one can model the swing effect based on physical or measured parameters. For example, Prolith (KLA-Tencor) allows the swing curve to be calculated.

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There are well known disadvantages to all these approaches. The most common method is to prepare wafers of varying resist thicknesses. This is very labor intensive and the resulting metric, dose to clear, or linewidth, versus resist thickness is typically very noisy due to other process variations. The single wafer approach requires that a topography wafer be fabricated which may not be representative of normal processing or easy to do for particular films.

The last approach listed is modeling. This is generally much easier to do than measuring the swing curve but it requires knowledge of many optical and physical parameters such as the refractive index. Generally, the best approach is to measure the swing curve on a simple substrate so that realistic parameters can be extracted. Thereafter, the swing effect on more complicated substrates can be modeled.

Description of Invention

The basic invention is to measure the uv reflectance spectra of a resist coated wafer. As shown below, the reflectance spectra can be used to extract meaningful parameters that enable the periodicity of the swing curve to be determined. A minimum number of resist coated wafers are required with this approach. Below the derivation of the approach is given.

An expression for the electric field, $E_{(x,y,z)}$, in a material exposed to radiation is given by Mack:

$$E_{(x,y,z)} = E_{(x,y)} \frac{\tau_{12}(e^{-i2\Pi n_2 z/\lambda} + \rho_{12}\tau_D^2 e^{i2\Pi n_2 z/\lambda})}{1 + \rho_{12}\rho_{23}\tau_D^2} \qquad (1)$$

where

$E_{(x,y)}$ Incident plane wave at the surface

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$$\rho_{12} = (n_1 - n_2)/(n_1 - n_2)$$
Reflection coefficient

$$\tau_{12} = 2n_1/(n_1 + n_2)$$
Transmission coefficient

$$\tau_D$$
Internal transmittance of the film

$$k_2 = 2\Pi n_2/\lambda$$
Propagation constant

$$n_j = n_j - ik_j$$
Complex index of refraction

$$n_{(\lambda)} = C_1 + \frac{C_2}{\lambda^2} + \frac{C_3}{\lambda^4}$$
Cauchy expansion for refractive index

Exposure intensity is proportional to the square of the electric field. Furthermore, the average intensity is proportional to the square of the electric field integrated over the thickness of the resist divided by the thickness. The measured reflectance spectra should have the same functional dependence on periodicity. Thus, reflectance intensity can be parameterized as:

$$I = g \quad f_{(\cos(4\Pi n_2 t/\lambda))} \tag{2}$$

where g is a function of optical constants of the substrate and resist and t is the resist thickness. The periodicity of the reflectance spectra is given by $\cos(4\pi n_2/\lambda)$. This is well known in the industry and is used to calculate thicknesses of thin films.

The method shown here consists of the following steps

1.   coat a wafer with resist on a simple substrate and measure the resist thickness. The resist thickness should be at the low side of the thickness range desired.

2.   using the same coat coat program, dispense resist on the substrate whose optimal thickness is desired.

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3. Measure the reflectance spectra in regions of interest near the actinic radiation

4. Extract the effective refractive index by fitting the periodicity of the reflectivity spectra to the form of Eq. 2

5. Using the effective refractive index near the actinic wavelength, predict the periodicity of the swing curve by keeping λ constant and varying t.

6. Repeat steps 1-5 with a wafer coated with resist thickness at the upper end of the desired thickness range.

7. Calculate the average predicted maxima and minima, weighted by the distance between the sample and the calculated peak.

Example Embodiment:

It is desired to determine the optimal resist thickness for SPR660 between 0.8 and 0.9μm on a film stack consisting of 1600A silicon nitride on 500A amorphous silicon on 300A pad oxide on silicon. Two wafers are coated with resist, one with 0.771 and the other with 0.896μm as measured by using the same coat program on bare silicon wafers. The UV reflectance spectra was recorded for both wafers and is shown in Fig. 1. Fig. 2 shows the UV spectra for the wafer coated with 0.771. There are many methods that can be used to fit the sinusoidal component of the reflectance spectra. The method used here was to extract the minima and maxima from each spectra and locally scale the data to ±1 based on neighboring peaks. A best fit was found by iterating the Cauch y refractive index constants. At the actinic wavelength, this provides the effective refractive index required to evaluate the periodicity of the standing effect on linewidth. For example, Table 1 shows the effective refractive indices regressed from the wafers coated with 0.771μm and 0.896μm.

After the effective refractive indices at the 365nm exposure wavelength are extracted from the

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reflectance spectra, the periodicity of the linewidth standing wave equation is computed from:

$$CD = A + BCos(4\Pi n_{365}^{Eff} t / \lambda)$$

Thus the peaks and valleys of the cosine argument are predicted to be the minima and maxima of the linewidth standing wave equation. Fig. 3 shows a comparison versus the actual measured swing curve measured on wafers of varying resist thicknesses. Note that the UV spectra coated at 0.771μm of resist more accurately predicted the maximum at 0.783μm while the UV spectra coated at 0.88μm predicted the second maximum better at 0.880μ.

In general, the closer in thickness the wafer is to the predicted minimum or maximum, the better is the prediction. A method of compensating for this is to analyze and extract effective refractive indices at the endpoints of the desired thickness range. The corrected minimum and maximum are then calculated as the average between these two predictions weighted inversely to their relative distances from the predictions. Table II summarizes the predictions, weighting factors and measured minima and maximum of the desired resist thickness range.

Of course, more than two resist thicknesses can be analyzed in the spirit of the procedure mentioned above. If more than two are analyzed than the algorithm for weighting the predictions will have to be modified.
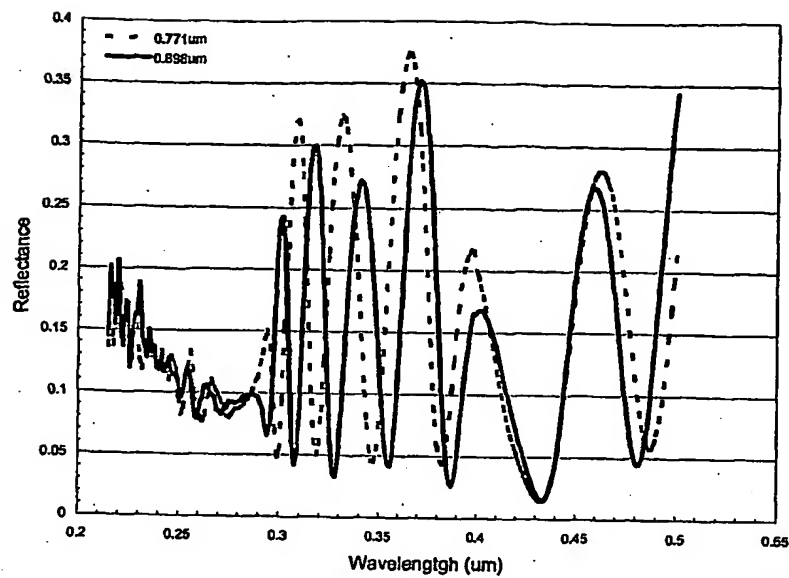
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Fig. 1   UV reflectance spectra at extremes of desired resist thickness range. The substrate is a poly buffer locus stack (silicon nitride/amorphous silicon/oxide/silicon)
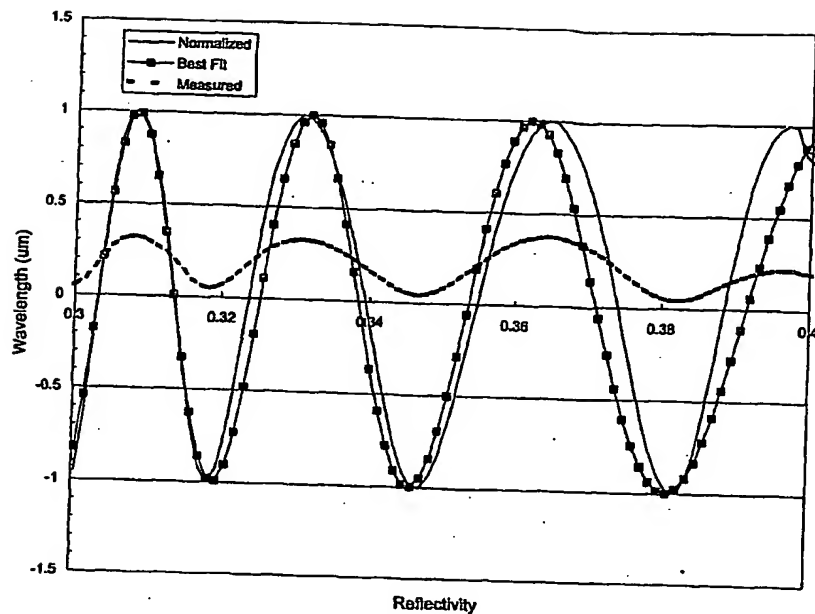
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Fig. 2 Measured UV reflectance spectra in the vicinity of the exposing wavelength. Cross plotted is the pure sinusoidal component normalized to ±1 and a best fit curve. The resist thickness was 0.771µm as measured on a bare silicon wafer

Table 1 Effective Refractive Indices at 365nm Regressed from UV Spectra

	0.771µm	0.88µm
n_{365}^{Eff}	1.874	1.853
Predicted Swing Maxima Thicknesses	0.780	0.788
	0.878	0.886

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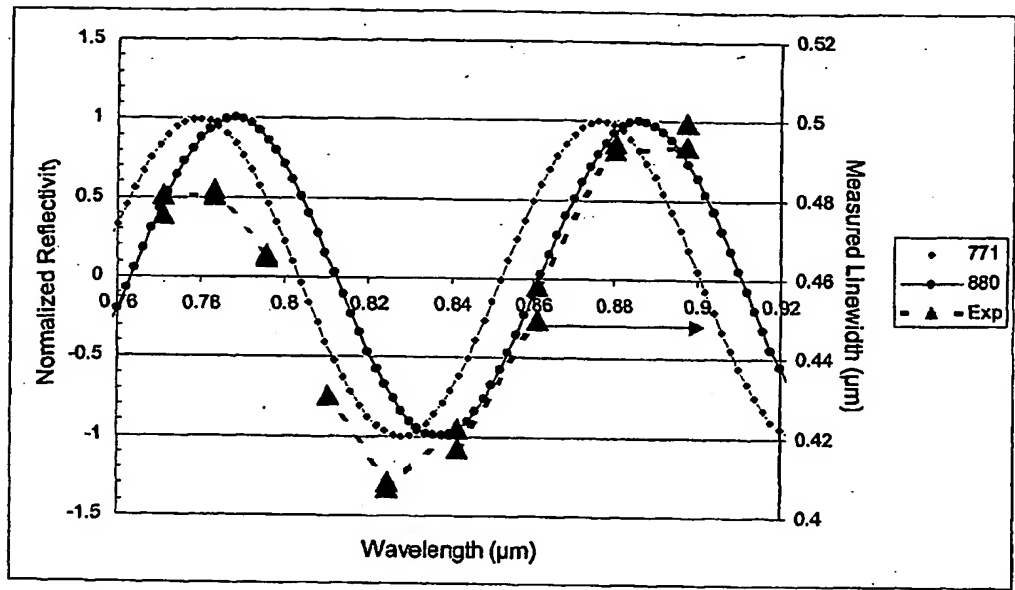| Predicted Swing Minima Thicknesses	0.828	0.838

Fig. 3 Predicted versus actual swing curve for SPR660 on poly buffer locos stack

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Table 2 Predicted and Measured Minima and Maxima

	0.771μm	0.88μm
First Maximum		
Predicted	0.780	0.786
Distance Coat to Prediction	0.010	0.094
Weight Factor	0.094/.104	0.01/.104
Weighted Prediction	0.781	
Measured	0.783	
Second Maximum		
Predicted	0.878	0.886
Distance Coat to Prediction	0.107	0.006
Weight Factor	0.006/0.113	.107/0.113
Weighted Prediction	0.886	
Measured	0.880	
First Minimum		
Predicted	0.828	0.838
Distance Coat to Prediction	0.057	0.042
Weight Factor	(0.042/.099)	(.057/0.099)
Weighted Prediciton	0.828	
Measured	0.825	

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Comparing Swing Curve Amplitudes

Background

Most semiconductor devices are fabricated by coating thin layers of photosensitive materials (resists) onto various substrates. These thin layers are exposed to radiation (usually ultraviolet) to induce chemical reactions which create regions that are either base soluble or base insoluble. Since these films are on the same order of thickness as the actinic radiation, the amount of light coupled into the resist is very dependent on the thickness. The effect of resist thickness on linewidth is known as the "swing curve" effect. In general, the swing curve effect is sinusoidal. It is very desirable to operate processes which have minimal linewidth variation due swing curve effects as to produce devices with nearly the same critical dimensions.

There are several methods to determine the swing curve. The first is to prepare wafers of varying resist thickness on well known substrates, typically silicon, measure the resist thickness and then expose and develop the wafers. After development, a particular feature is measured on all the wafers and its dimension is tabulated or plotted as a function of resist thickness. This generally results in a sinusoidal curve. A second method is to expose a pattern of increasing exposure doses on wafers of varying thicknesses and record the dose for each wafer at which the resist clears or has the same optically measured thickness. A single wafer version of this method is to induce topography, by selective etching, so that when coated there is a variation of thicknesses across the wafer. The resist thickness in these regions is measured and then the wafer is exposed, developed and measured. Linewidth or dose to clear measurements are compared to the resist thicknesses before exposure. Lastly, one can model the swing effect based on physical or measured parameters. For example, Prolith (KLA-Tencor) allows the swing curve to be calculated.

There are well known disadvantages to all these approaches. The most common method is to

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prepare wafers of varying resist thicknesses. This is very labor intensive and the resulting metric, dose to clear, or linewidth, versus resist thickness is typically very noisy due to other process variations. The single wafer approach requires that a topography wafer be fabricated which may not be representative of normal processing or easy to do for particular films.

The last approach listed is modeling. This is generally much easier to do than measuring the swing curve but it requires knowledge of many optical and physical parameters such as the refractive index. Generally, the best approach is to measure the swing curve on a simple substrate so that realistic parameters can be extracted. Thereafter, the swing effect on more

complicated substrates can be modeled.

Description of Invention

The basic invention is to measure the uv reflectance spectra of a resist coated wafer at a nominal thickness. After coating, the uv reflectance is measured and the peak heights and valleys in the vicinity of the actinic wavelength are tabulated. The relative swing ratio is computed as the average peak height of the spectra at the exposure wavelength. This relative swing ratio can be compared to similar computations on other processes to determine which provides the best critical dimension control. This will be illustrated below.

Fig. 1B shows the UV reflectance spectra of two resist films on a poly buffer locos stack (1600A SiN/ 500A amorphous silicon/300A SiO_2/silicon substrate. The first resist resist film is SPR660 while the second is SPR660 covered with Aquatar II which is a top antireflecting film (TARC) that is designed to suppress standing waves. In one application of this patent, it is desirable to quantitatively and quickly compare the swing ratios of both processes. These resist films are normally exposed using I-line (365nm) lithography.

The wavelengths at which the peaks and valleys of both spectra were tabulated. Table 1B shows results for the 0.771μm film without TARC from Fig. 1B. Since the amplitudes of the spectra are not perfectly periodic due to substrate and other effects, the peak height was calculated as the average of nearby peaks. For the case in which the actinic wavelength is nearest to or at or a

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maximum and (see Fig. 2), the relative swing amplitude, A_r, was calculated as:

$$A_r = [(Max_1 + Max_2)/2 - Min_1]/2 \qquad (1b)$$

Alternatively, if the actinic wavelength is closest to a minimum than the following averaging was used:

$$A_r = [Max1 - (Min1 + Min2)/2]/2 \qquad (2b)$$

Note that there are many different ways of determining the average peak height without violating the spirit of this disclosure.

Table 2B shows the swing ratio calculation for many wafers at various resist thicknesses, with and without Aquatar TARC. Note that the SR calculation is relatively independent of resist thickness but depends on whether aquatar was used or not. The swing reduction ratio, S_r, can be calculated from the UV spectra:

$$S_r = (A_r^{NoAquatar} - A_r^{Aquatar}) / A_r^{NoAquata} \qquad (3b)$$

Alternatively, from experimental or modeling:

$$S_r = ((CD^{Max} - CD^{Min})^{No\ Aquatar} - (CD^{Max} - CD^{Min})^{Aquatar}) / (CD^{Max} - CD^{Min})^{No\ Aquatar} \qquad (4b)$$

In principle, the above method allows the linewidth variation with resist thickness to be calculated from two wafers without doing any linewidth measurements.
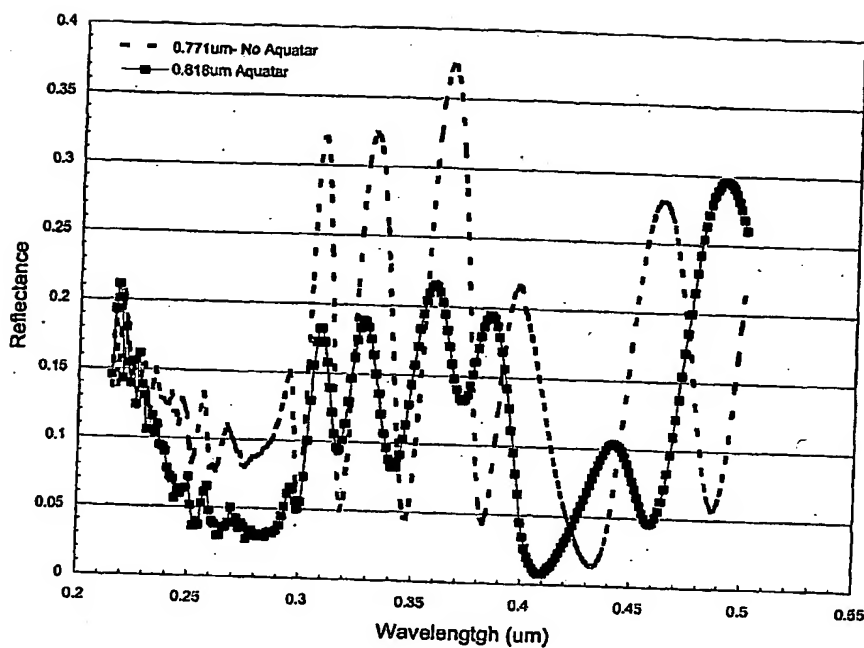
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Fig. 1B UV reflectance spectra at extremes of desired resist thickness range. The substrate is a poly buffer locus stack (silicon nitride/amorphous silicon/oxide/silicon)

Table 1B. Peaks and Valleys for the 0.771µm thick SPR660 film without TARC

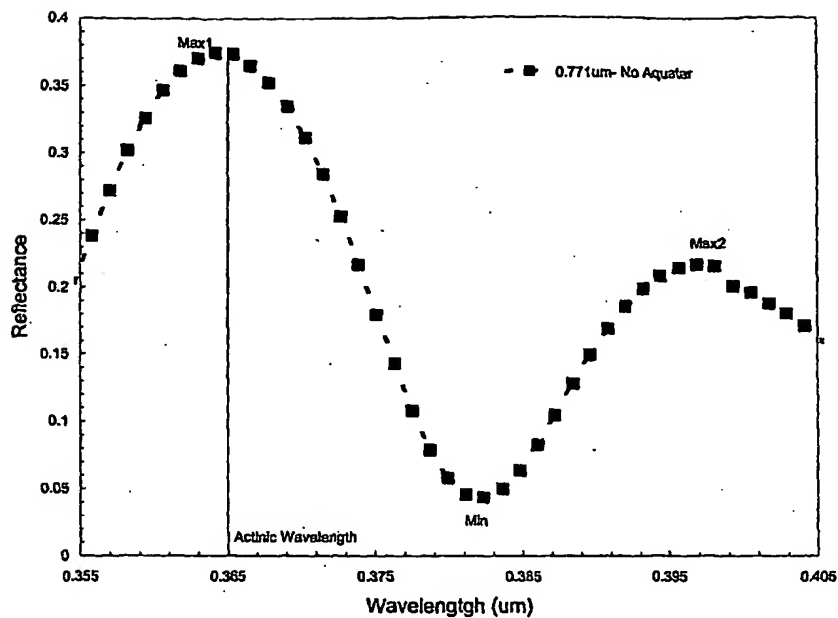| Peak/Valley	Reflectance
0.309	0.320
0.318	0.050
0.330	0.324
0.347	0.045
0.364	0.375
0.382	0.044
0.397	0.217
0.433	0.014
0.462	0.280
0.487	0.057

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Fig. 2B. Peak heights and a minimum in the vicinity of the exposure wavelength

File	Description	Thickness(μm)	A_r
3924911.asc	Aquatar	0.771	0.043
3925507.asc	Aquatar	0.783	0.046
3925515.asc	Aquatar	0.796	0.054
3925503.asc	Aquatar	0.825	0.059
3925523.asc	Aquatar	0.842	0.054
3924908.asc	Aquatar	0.861	0.048
3925511.asc	Aquatar	0.880	0.042
Average			0.050
3924901.asc	No Aquatar	0.771	0.165
3925505.asc	No Aquatar	0.783	0.150
3925513.asc	No Aquatar	0.796	0.141
3925525.asc	No Aquatar	0.811	0.141
3925501.asc	No Aquatar	0.825	0.138
3924905.asc	No Aquatar	0.861	0.147
3925509.asc	No Aquatar	0.880	0.136
3925517.asc	No Aquatar	0.897	0.135
Average			0.141

Table 2B Relative peak amplitude calculations from UV spectra

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	Swing Reduction
Spectra	(0.141-0.050)/.141=.33
CD Measurements	(0.033-0.019)/0.033=.21

Table 3B   Calculation of swing curve reduction ratios

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CLAIMS

1.   A method for comparing swing curve amplitudes on a wafer substrate, comprising:

coating the wafer substrate with a photo-resist, the resist being applied at a predetermined thickness;

measuring the ultraviolet (UV) reflectance spectra of a resist coated wafer, the UV reflectance spectra comprising peaks and valleys having each having an actinic wavelength;

tabulating heights and depths of the peaks and valleys;

computing a relative swing ratio as a function of average peak height of the spectra at the exposure wavelength.

2.   The method of claim 1 further comprising,

comparing the relative swing ratio of a first process with a relative swing ratio of a second process; and

determining which process provides better critical dimension control.

3.   A method for measuring resist film thickness on a wafer substrate, comprising:

a). programming a resist dispenser to deposit a coat of resist at first predetermined thickness, the first predetermined thickness being at the low end of a desired range.

b). depositing a coat a first wafer with resist at the first predetermined thickness;

c). measuring the thickness of the resist on the first wafer and obtaining a measured first thickness;

d). programming the resist dispenser to deposit resist at the measured first thickness;

e). depositing a coat of resist at the first measured thickness on a second wafer;

(f). measuring the ultraviolet (UV) reflectance spectra of the resist on the second wafer; the UV reflectance spectra comprising peaks and valleys having each having an actinic wavelength;

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(g). extracting an effective refractive index as a function of the periodicity of the reflectivity spectra, wherein the function is defined as: $I = g\ f_{(\cos(4\Pi n_2 t / \lambda)}$

where g is a function of optical constants of the substrate and resist and t is the resist thickness, and the periodicity of the reflectance spectra is given by $\cos(4\pi n_2/\lambda)$; and

(h). predicting the periodicity of the effective refractive index at a wavelength near the actinic wavelength, wherein the periodicity of the swing curve is determined by keeping λ constant and varying t

4.   The method of claim 3 further comprising,

(i). programming a resist dispenser to deposit a coat of resist at second predetermined thickness, the first predetermined thickness being at the high end of a desired range.

(j). depositing a coat a second wafer with resist at the first predetermined thickness;

(k). measuring the thickness of the resist on the second wafer and obtaining a measured second thickness;

(l). repeating steps f). through h); and

(m). calculating average predicted maxima and minima as a function of a weighted distance between spectral peaks obtained from the measured wafers and a calculated peak.

5.   System for comparing swing curve amplitudes on a wafer substrate, comprising:

means for coating the wafer substrate with a photo-resist, the resist being applied at a predetermined thickness;

means for measuring the ultraviolet (UV) reflectance spectra of a resist coated wafer, the UV reflectance spectra comprising peaks and valleys having each having an actinic wavelength;

means for tabulating heights and depths of the peaks and valleys;

means for computing a relative swing ratio as a function of average peak height of the spectra at the exposure wavelength;

means for comparing the relative swing ratio of a first process with a relative swing ratio

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of a second process; and

means for determining which process provides better critical dimension control.

6. System for measuring resist film thickness on a wafer substrate, comprising:
means for programming a resist dispenser to deposit a coat of resist at first predetermined thickness, the first predetermined thickness being at the low end of a desired range.

means for depositing a coat a first wafer with resist at the first predetermined thickness;

means for measuring the thickness of the resist on the first wafer and obtaining a measured first thickness;

means for programming the resist dispenser to deposit resist at the measured first thickness;

means for depositing a coat of resist at the first measured thickness on a second wafer;

means for measuring the ultraviolet (UV) reflectance spectra of the resist on the second wafer; the UV reflectance spectra comprising peaks and valleys having each having an actinic wavelength;

means for extracting an effective refractive index as a function of the periodicity of the reflectivity spectra, wherein the function is defined as: $I = g \ f_{(\cos(4\Pi n_2 t / \lambda)}$ where g is a function of optical constants of the substrate and resist and t is the resist thickness, and the periodicity of the reflectance spectra is given by $\cos(4\pi n_2/\lambda)$; and

means for predicting the periodicity of the effective refractive index at a wavelength near the actinic wavelength, wherein the periodicity of the swing curve is determined by keeping λ constant and varying t

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ABSTRACT

In an example embodiment, there is a method for measuring UV (ultra-violet) reflectance spectra of a resist-coated wafer. The reflectance spectra may be used to extract meaningful parameters that enable the periodicity of the swing curve to be determined. A minimum number of resist-coated wafers are required with this approach. In another example embodiment, there is a method for measuring the UV reflectance spectra of a resist-coated wafer at a nominal thickness. After coating, the UV reflectance is measured and the peak heights and valleys in the vicinity of the actinic wavelength are tabulated. The relative swing ratio is computed as the average peak height of the spectra at the exposure wavelength. This relative swing ratio can be compared to similar computations on other processes to determine which provides the best critical dimension control.

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